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Use of an Analytical Theory for the Physical Libration of the Moon to Detect Free Nutation of the Lunar Core

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Abstract—A brief review of modern observational achievements and the theoretical basis of physical libration of the Moon is presented. Special attention is given to the inferred existence of a lunar core and determination of its parameters. The creation of a theory of physical libration of the Moon, which requires analyses of semi-empirical series of long-term laser observations and the use of the highly accurate DE421 dynamical ephemeris, is related to this. A large role in this area has been played by the analytical theory of physical libration of the Moon constructed by Yu.V. Barkin, which made it possible for the first time to derive parameters of the free nutation of the lunar core from observations. This paper is based on a talk given at the conference "Modern Astrometry 2017," dedicated to the memory of K.V. Kuimov (Sternberg Astronomical Institute, Moscow State University, October 23–25, 2017).

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1. INTRODUCTION

The investigation of the internal structure of celestial bodies is a task facing scientists working in a variety of areas. A huge observational database has been accumulated for the Moon, including both traditional ground (heliometric and photographic) observations [1], seismic sounding using lunar surface modules [2, 3], theoretical and computer modeling based on the multi-faceted reduction of various types of data [4], and the most powerful source of information about the Moon—laser ranging using corner reflectors installed on the lunar surface in the 1960s [5–7].

Recent space missions and progress in studies of the lunar gravitational field have provided the conditions needed for the construction of highly accurate theories of the lunar rotation. For example, the Selene mission (Japan, 2007–2009) made it possible to appreciably refine the Stokes coefficients of orders two to four in expansions of the lunar potential, which most strongly influence the physical libration of the Moon (PhLM). Furthermore, new observational technologies in a system of three circumlunar satellites have enabled the refinement of the Love coefficient k_2, responsible for the visco-elastic properties of the lunar body [8, 9].

An improved model for the gravitational field based on data from the American GRAIL mission (2011–2012) [10, 11] is incorporated in the best numerical ephemeris of the Moon and the planets current available, DE430/431 [12], which provides submeter precision when compared with laser-ranging data.

All this variety of astronomical and geophysical methods has provided a reliable observational basis for studies of the structure of the Moon's body and its physical and chemical properties.

2. NUMERICAL AND ANALYTICAL APPROACHES IN THE THEORY OF PHYSICAL LIBRATION OF THE MOON

The results of theories of PhLM can be represented in various ways: as tables containing the results of numerical integrations or Poisson series determining the analytical dependences on time and the parameters of the dynamical figure of the Moon. Several analytical and numerical theories have been constructed over roughly the past 40 years (see Table 1), which have been used to achieve the precision required to implement lunar space projects and predict and describe many subtle effects in the Moon's rotation.

The series of the presented numerical ephemerides are the most complete, all have the same accuracy, and are adequate for modern radio technical and laser observations. A numerical approach makes it possible without particular mathematical problems to refine the model for the internal structure of the Moon

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